LASSO, two-way and GPS time comparisons: a (very) preliminary status report

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Abstract

This very preliminary report briefly presents the first results on the time transfer experiments between TUG (Graz, Austria) and OCA (Grasse, France) using common view GPS, and two-way stations at both sites. The present data, providing a rms of the clock offsets of 2 to 3 nanoseconds for a three months period, have to be further analysed before any conclusions on the respective precision and accuracy of these techniques can be drawn.

Two years after its start, the LASSO experiment is finaly giving its first results at TUG and OCA. The first analysis of three common sessions permitted us to conclude that the LASSO package on board of Meteosat P2 is working staisfactorily, and that time transfer using this method should provide clock offsets at better than 1 nanosecond precision, and clock rates at better then 10^{-12} s/s in a 5 to 10 minutes session. A new method for extracting this information from the raw data sent by LASSO should enhance the performances of this experiment, exploiting the stability of the on-board oscillator.

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1 - Introduction

After the failure of the SIRIO 2 launch, and the subsequent unavailability of the LASSO experimental equiipment package (hereafter referred to as LASSO), a new phase started in Summer 1988, when a new geosynchronous satellite, Meteosat P2, carrying a new LASSO experiment, was launched successfully. In spite of the work made at various sites in order to obtain results from LASSO data, and after a short move of the satellite across the Atlantic (up to 50° W) and back to 0° in early 1990, no real results were obtained before November 1990.

During 1990, in order to compare various techniques transfering time at a few nanoseconds supposed accuracy, GPS and two-way time transfer were achieved between TUG (Graz, Austria) and OCA (Grasse, France). The first, very preliminary, results of these GPS and two-way results will be given. But most of this presentation will be devoted to LASSO.

2 - Two-way and GPS

With the help of NIST and USNO, a VSAT two-way time transfer equipment has been installed close to the laser stations on the «Plateau de Calern», observing site of the «Observatoire de la Côte dAzur» (hereafter OCA). With a dish of 1.8m in diameter, it permitted us to achieve common sessions three times a week with TUG (Graz, Austria) starting on June 22, 1990.

A typical clock offset measurement plot is shown on Fig. 1. The rms value of the offsets (a linear fit has been made through the data) is 0.7 ns. Most of the sessions are at this level of precision, smaller rms values being obtained using larger dishes (like in the NIST/USNO experiments).

At the same time, GPS time transfer using common view satellites has been performed. Fig.

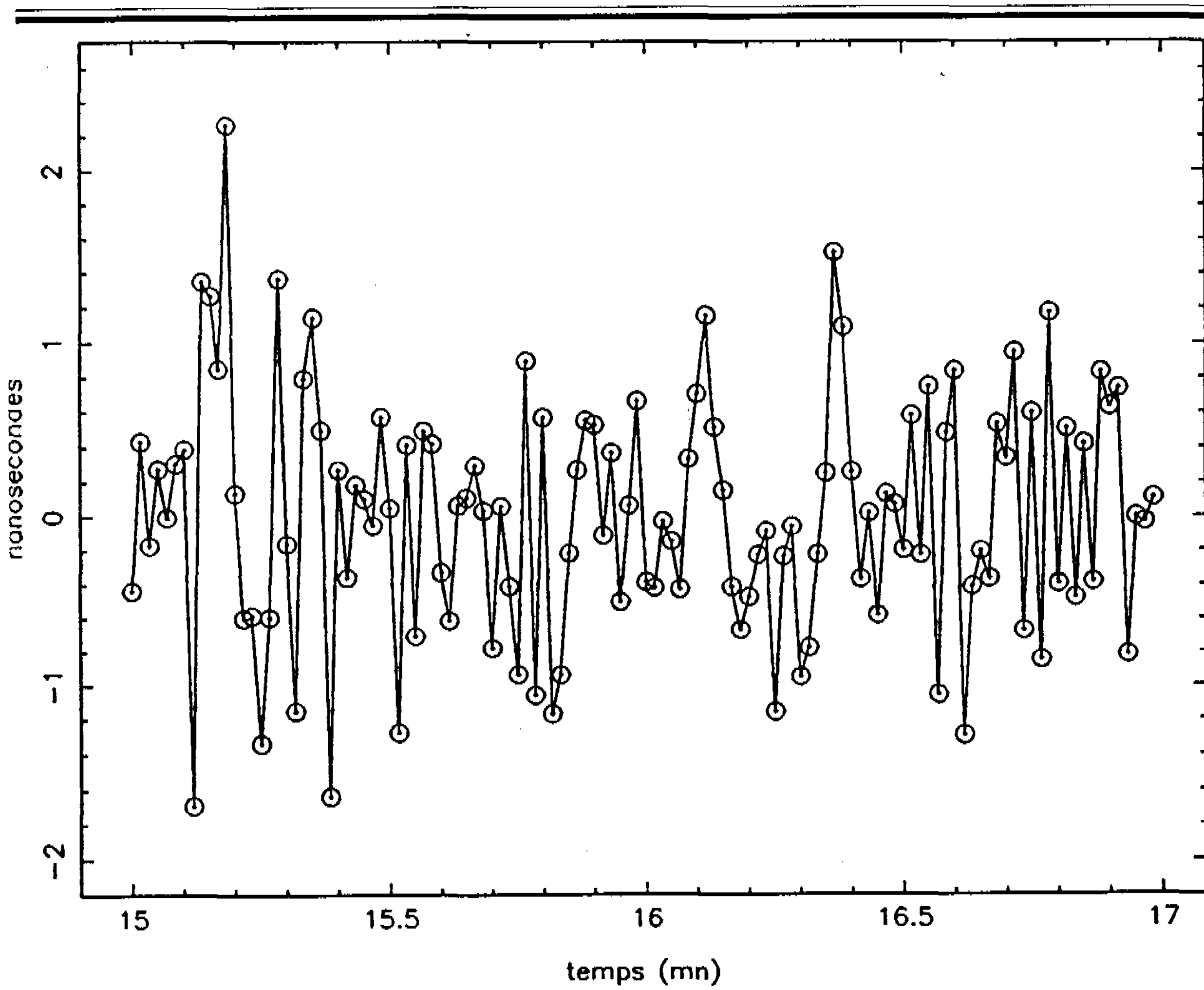

Fig. 1 - *A two minutes two-way session between TUG and OCA (1990 Nov 9). Each point is a clock offset measurement. A linear fit has been made through the data. The rms of the values around the fit is 0.70 ns.*

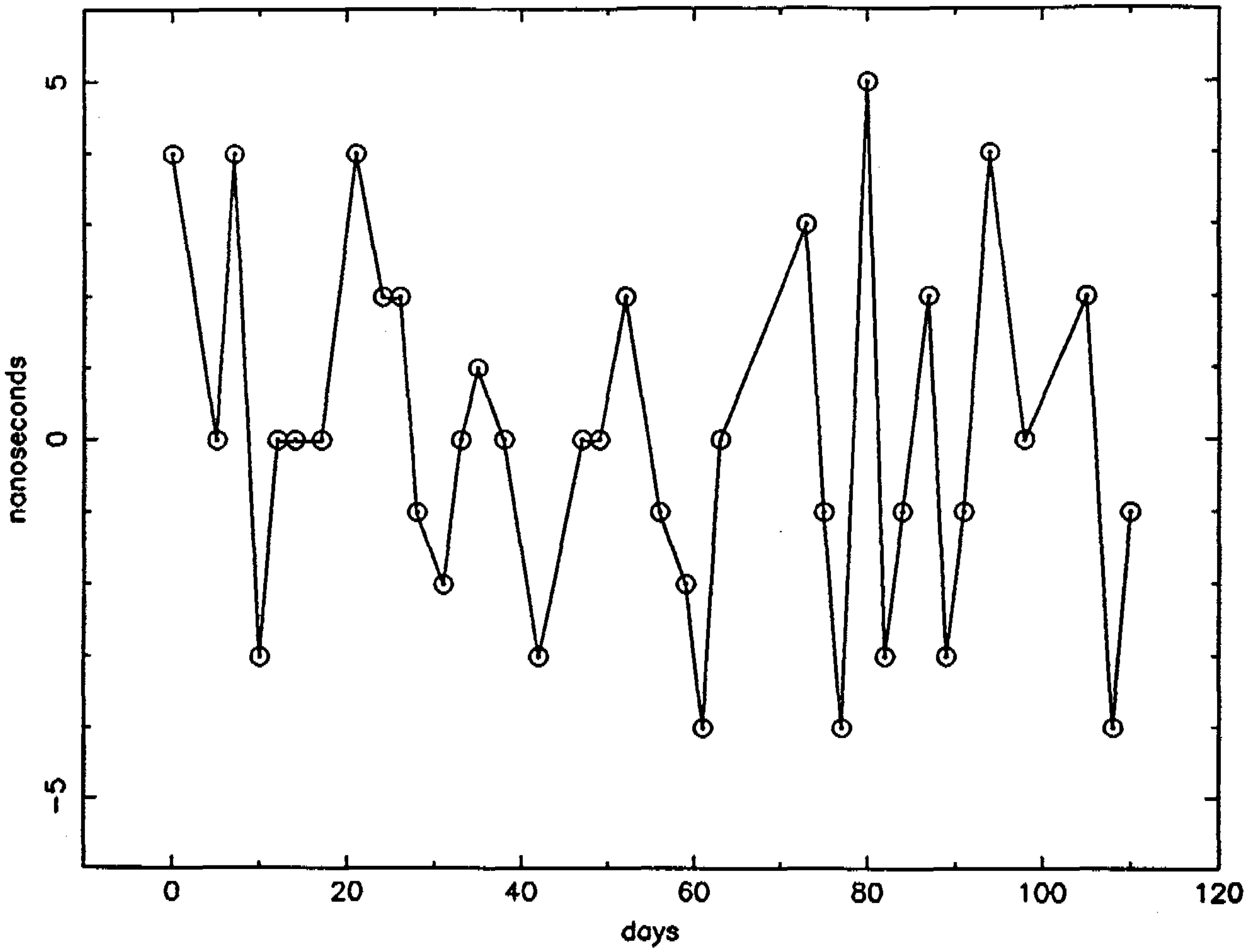

Fig. 2 - *Plot of the clock offsets differences determined using GPS and two-way at TUG and OCA. The period shown covers three months from 1990 June 22 up to October 10. The rms of the differences (bias removed) is 2.5 ns..differences*

2 shows a plot of the differences of the clock offsets obtained using both the GPS and two-way techniques. These results are very preliminary. Many things have to be looked at, especially the way in which the GPS data are interpolated to match the epoch of the two-way sessions. More on this analysis will be presented in a subsequent paper.

3 - LASSO

3.1 - How does it work ?

On board a geosynchronous satellite, Meteosat P2, an active package is able to detect and record oby an event-timer the arrival time of a laser pulse sent from a ground-based station. Retroreflectors, installed above the receiver, send back to the transmitting station part of the incoming light, so that the station can record the start and return time of the laser pulse.

Both firing and echo times are measured using the station time scale, but the detection time on board of Meteosat is determined using an oscillator which is stable enough to insure that there will be a drift of less than one nanosecond in a few milliseconds. For comparing the time scales at two different Earth stations, it is sufficient to organize the firing times at both sites so that the arrival times at LASSO be within a few milliseconds. By its specifications, the on-board oscillator should not introduce any error at the nanosecond level. Direct clock comparison is achieved every time two pulses from two different stations give two detection times on board the satellite in a common window (that is, within a few milliseconds ...), when one also has an echo time at each participating station. Fig. 3 gives a schematic view of the time transfer method used for LASSO.

3.2 A brief review of the LASSO experiment steps since 1988 ...

A short time after the launch of

Meteosat P2, echoes were obtained at the OCA Lunar Laser Ranging station. A few months were sufficient to be sure that the LASSO package was working properly, after the correction of encoding errors in the data transmission between the satellite and the Earth. With the time passing and the attempts from various sites remaining unsuccesfsul, it became clear that only a few stations were able to get echoes from Meteosat P2. Beside the OCA Lunar Laser Ranging (LLR) station, for which a satellite, even geosynchronous, is an easy target, only the TUG satellite station, equipped especially for LASSO with a ruby laser, and the Katzively station (Crimea, USSR), (another potential LLR site), can really contribute to LASSO as a two-way station. Both of these stations are able to get both detection on-board Meteosat, and echoes from its retroreflectors.

The first echoes, as well as on-board detections, were obtained with TUG station in September 1989. In late October 1989, Meteosat P2 was moved to 50° West, in order to provide meteorological information to the United States. Two stations (Mc Donald, Texas, and University of Maryland / Goddard Space Flight Center optical facility, Greenbelt, Maryland) started to study how to work with LASSO, and OCA LLR station obtained echoes in spite of the very low position of the satellite as seen from Grasse (17° elevation). Meteosat P2 started a journey back over Europe in late December 1989, and a new European phase of LASSO has been organized in January 1990.

Due to various problems in Graz, only OCA LLR station ranged successfully LASSO between January and August. TUG was back at work at that time, as well as Katzively. The latter station got echoes in September, and the first common sessions with both TUG and OCA finally succeeded on 1990 November 7 and 8.

3.3 The first results

The following analysis has been made using the processing of the satellite raw data files made at OCA for the sessions of November 7 and 8 1990.

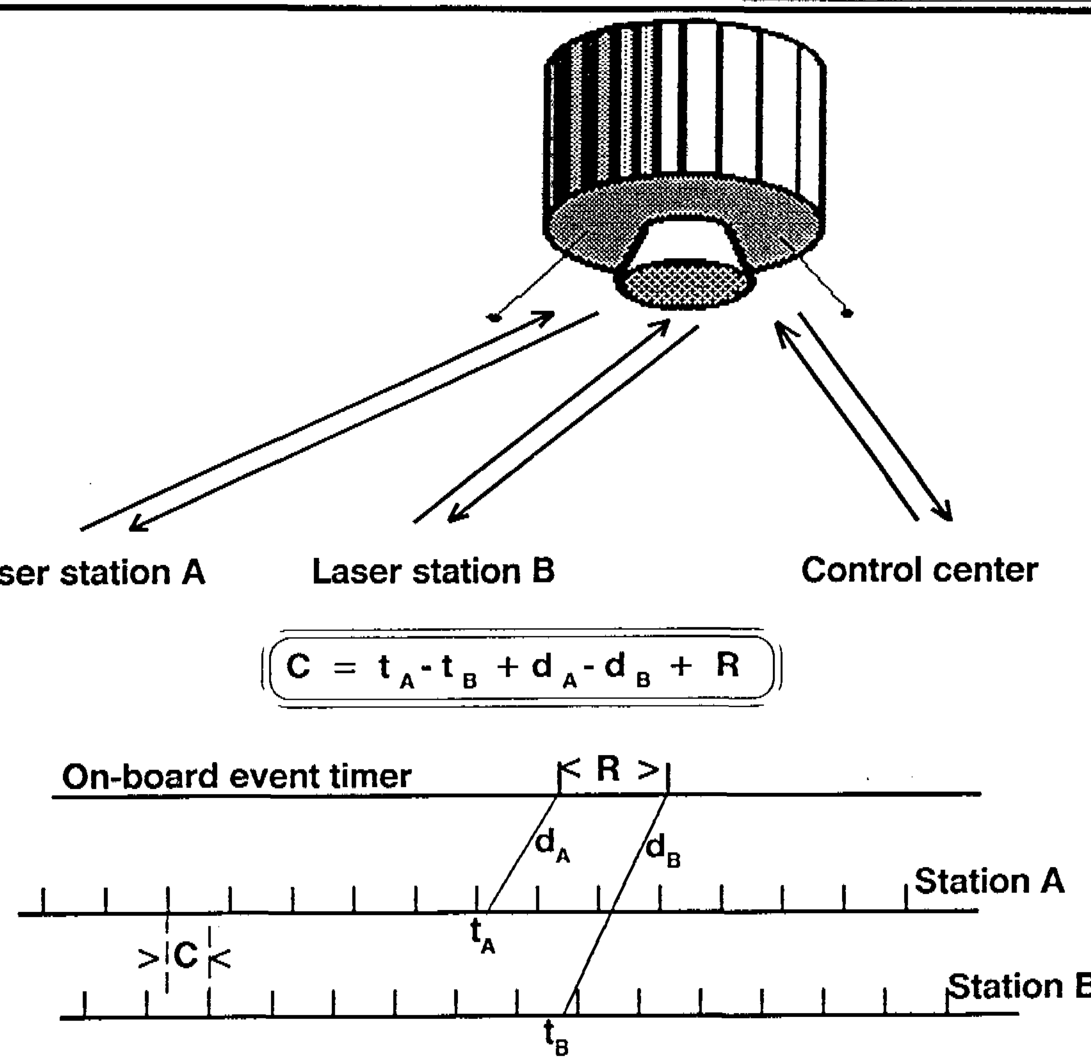

Fig. 3 - *A schematic view of the LASSO experiment. The time transfer is performed through the on-board oscillator which provides an intermediate time scale for the determination of the offset of the station clocks.*

From these files, and using the station data , it is possible to identify triplets, i.e. laser pulse start time, detection time on LASSO and echo time back at the considered station, for a given session typically 10 minutes long. These triplet data lead to the identification of common windows, a couple of triplets from TUG and OCA with close detection times on the satellite.

In order to check the quality of the LASSO package in terms of time stability, the echo times have been analysed, and compared to the detection times (on the on-board time scale) at a given station. Fig. 4 show show these echo times look for TUG as a function of the firing times. The high rms found after a polynomial fit is as high as the rms values found using the detection times with the same data. IIt simply reflects the fact that TUG used at that time (this is no longer the case) an event timer with only a 10 ns resolution. The same analysis with OCA results (Fig. 5 and 6) shows that the rms values for the detection times (in LASSO time scale) is only twice as large as that for the echo times (in station time scale), and still much below 1 ns. The conclusion is that the LASSO equipment doesn't degrade too much the laser signal, and is really suitable for a sub-nanosecond timing.

Using these triplets, only 12 common windows have been found for November 8 first session. It leads to 12 individual clock offset determinations which are plotted on Fig. 7. The rms of these values against a linear fit over the four minutes of the run is 4 ns, and comes mainly from the poor resolution of the Graz time measurements at the time of the session. The same analysis made on three sessions on November 7 yields to a rms of 5 ns over 100 minutes and 12 common windows.

3.4 Another approach

Since the beginning of LASSO in 1988, it appeared from the detection times recorded on board that the oscillator is quite stable over 10

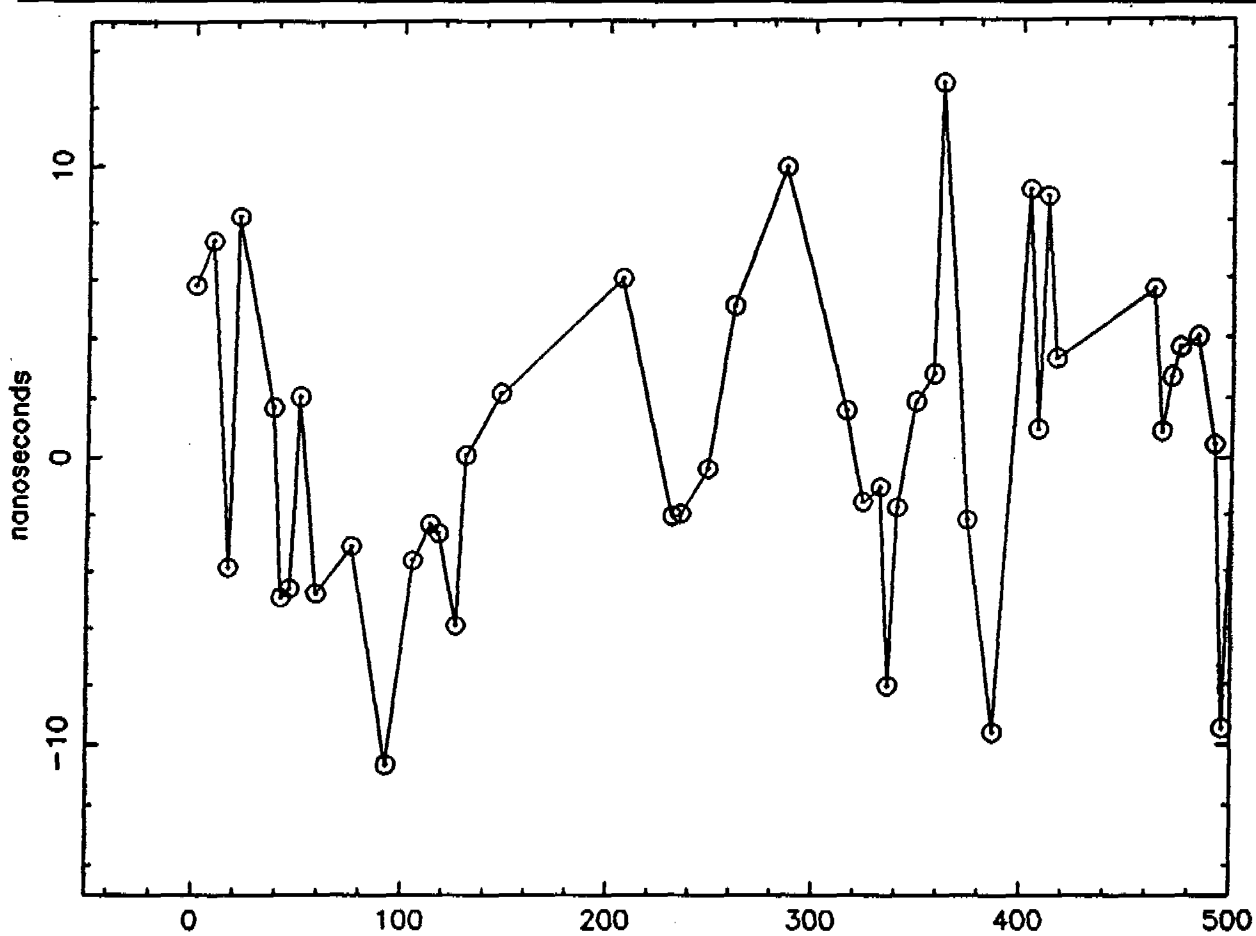

Fig. 4 - *Plot of the residuals on the range measurements relative to a polynomial fit - First session on 1990 Nov. 8 - TUG data. The high rms, 4.7 ns, reflects the poor resolution (10 ns) of the event-timer used at that time in*

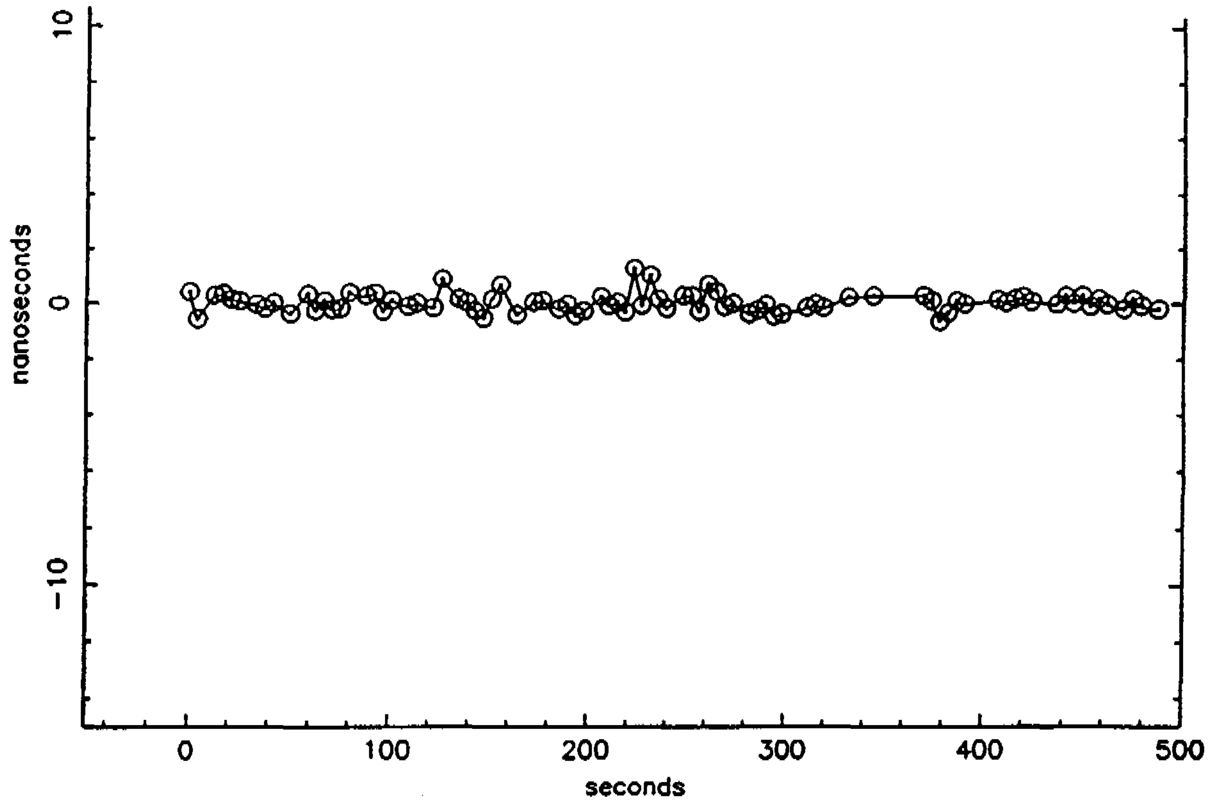

Fig. 5 - *Plot of the residuals on the range measurements relative to a polynomial fit - First session on 1990 Nov. 8 - OCA data. The rms, 0.33 ns, is typical of ranging measurements made on satellites with the OCA/CERGA Lunar Laser Ranging station.*

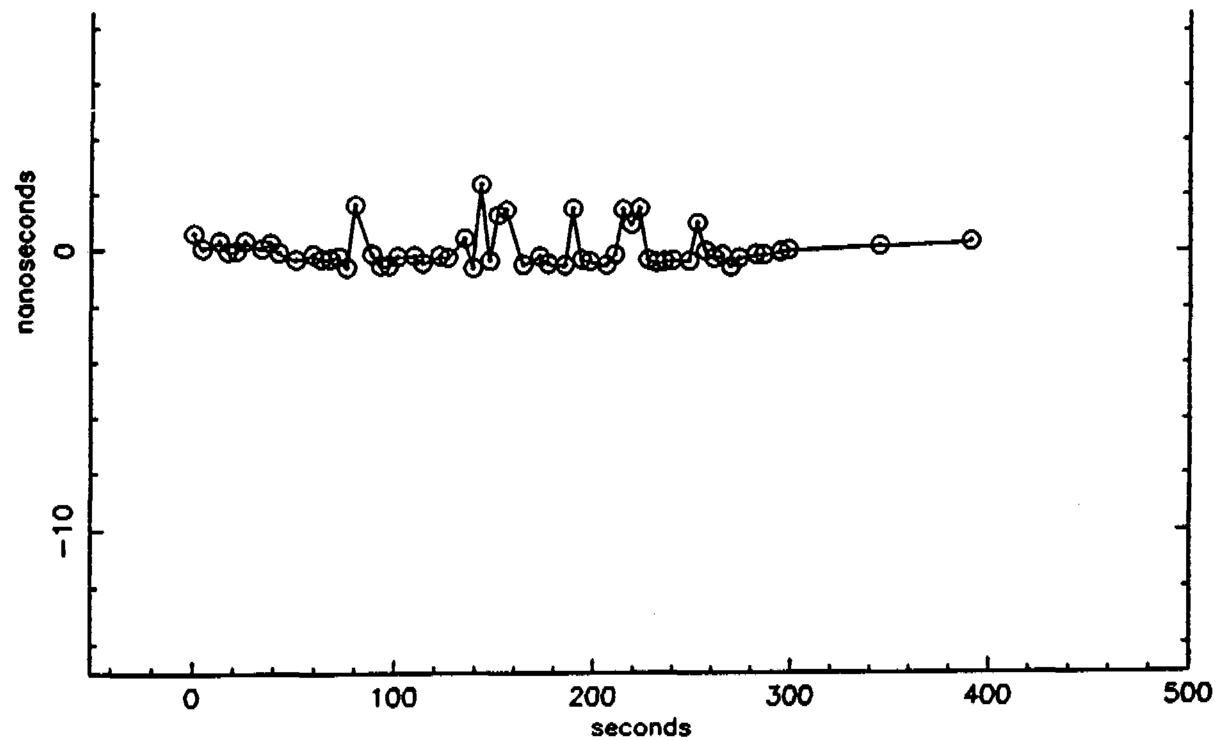

Fig. 6 - *Plot of the residuals on the on-board detection times as a function of the firing times relative to a polynomial fit - First session on 1990 Nov. 8 - OCA data. The rms, 0.67 ns, is only twice as large as that for the echo times. It shows that the jitters on board of LASSO are largely at a sub-nanosecond level, and that the oscillator has no suspect behaviour.*

minutes. As only a small number of common windows are seen in a session (12 for 10 minutes on November 8, 1990), an other treatment of the data was made at OCA in order to exploit the high number of triplets obtained (37 from TUG and 59 from OCA) and to use the good quality of the observerd LASSO time scale. At every session (5 to 10 minutes), the triplets from a given station are used for determining both the LASSO oscillator rate and the offset relative to the on-site clock. The difference between the clock offsets relative to the same LASSO scale will provide the clock offset between the two stations. The rate of a clock compared to the other one could also be determined if the data are sufficiently accurate, or the analysis could enforce the clock rates at the two sites to be equal.

Table 1 presents the results of this global analysis using the sessions on November 7 and 8 compared to those obtained with the common windows analysis previously planned for LASSO analysis. It is clear that the uncertainty on the clock offsets is much smaller with the global analysis, mainly because the number of data used is much larger. The TUG poor timings doesn't permit to reach the precision of LASSO. This precision should, from the results obtained using OCA data, be less than half a nanosecond for the clock offset, and 10^{-12} s/s for the clock rate.

3.5 Conclusion

Experiments in the near future, with a TUG station using a subnanosecond resolution event timer, should confirm that a time transfer at a subnanosecond level can be achieved with LASSO. Other stations could be involved, like Katzively (USSR) and Wettzell (Germany). After a calibration of the three methods used simultaneously, (GPS, two-way and LASSO), a comparison of their precision and accuracy could be possible at the nanosecond level, assuming that a H_2 maser is available at the concerned stations. As both two-way time transfer and

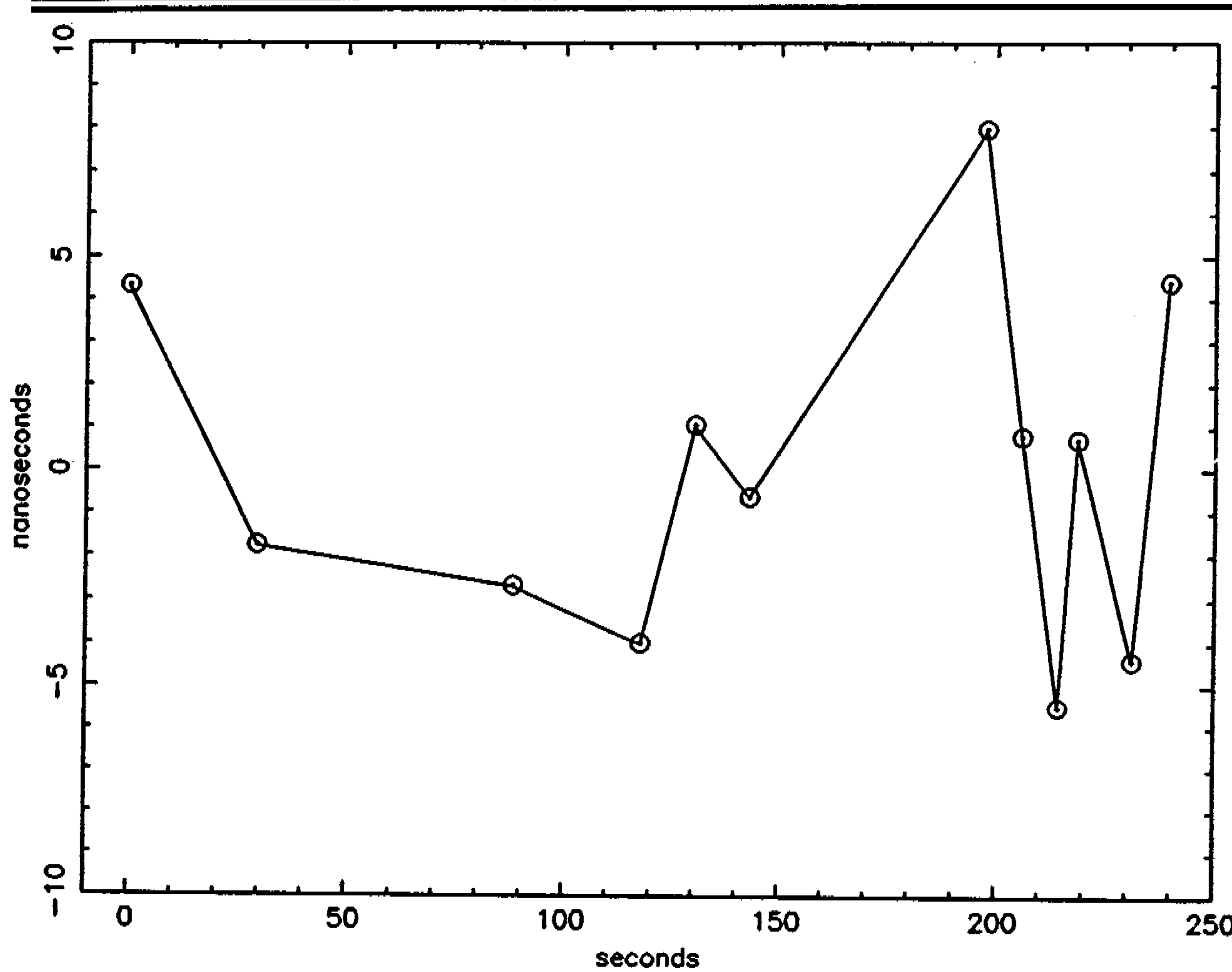

Fig. 7 - *Plot of the clock offsets between TUG and OCA determined using 12 LASSO common windows on the first session of 1990 Nov. 8. The scatter of the results is mainly dominated by the poor TUG timing resolution at the time of the session.*

LASSO act like a snapshot of the clock offset at a given epoch, the only way to compare them at the nanosecond level is to employ a time keeping device, like a maser, able to reach less than one nanosecond over two or three days. However OCA and Wettzell are the only sites at which a maser is in operation.

In the middle of 1991, Meteosat P2 could be moved again at 50° West, permitting a time transfer experiment between Europe (OCA) and United States. Waiting for this eventual move, the months to come will be used as much as possible to achieve time transfer between the European sites able to range Meteosat P2.

	1990 Nov. 7			Nov. 8
Session time (UTC)	**19h 25**	**19h 45**	**22 h 05**	**19h 35**
Triplet number OCA	**15**	**23**	**61**	**59**
" " TUG	**37**	**18**	**17**	**37**
With same clock rate at TUG and OCA				
LASSO clock rate (ps/s)	**-10252.7**	**-10228.5**	**- 10240.2**	**- 10239.6**
uncertainty	**6.8**	**9.3**	**1.7**	**2.6**
Clock offset (ns)	**8059.0**	**8060.6**	**8053.5**	**6006.6**
uncertainty	**1.6**	**1.3**	**0.7**	**0.7**
With different clock rates at TUG and OCA				
LASSO / OCA rate (ps/s)	**- 10248.9**	**- 10246.5**	**- 10238.7**	**- 10246.8**
uncertainty	**2.3**	**1.5**	**0.4**	**0.9**
LASSO / TUG rate (ps/s)	**- 10252.8**	**- 10215.3**	**- 10249.5**	**- 10235.9**
uncertainty	**8.6**	**18.1**	**9.8**	**5.1**
Clock offset (ns)	**8059.3**	**8060.6**	**8053.3**	**6006.6**
uncertainty	**1.0**	**1.5**	**1.3**	**0.9**

Table 1 - *Preliminary global analysis of the four sessions on 1990 Nov. 7 and 8, where data were obtained at TUG, OCA and on-board Meteosat P2. Each session is 5 to 10 minutes long. Further studies have to be made on the processing of these first LASSO data, but these preliminary results demonstrate that LASSO time transfer is possible at subnanosecond level, and clock rate measurements in a session at better than 10^{-12}.*